Control Based on Brain-Computer Interface Technology for Video-Gaming with Virtual Reality Techniques

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Szczepan Paszkiel

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Abstract:
The paper describes possibilities of application of brain-computer interface technology in neurogaming. To that end number of experiments were conducted in the Laboratory of Neuroinformatics and Decision Systems of the Opole University of Technology using Emotiv EPOC+ NeuroHeadset. Moreover, the paper presents an aspect of possibility of using brain-computer interface (BCI) technology in combination with virtual reality for controlling avatars/object in videogames.

Keywords: *neurogaming, brain computer-interfaces, virtual reality*

1. Introduction

A positive impact of neurogaming on human body has been confirmed in practice by its use for executing brain neuroplastic abilities for given purposes. Brain work changes depending on the activity of a given individual during specific time interval. Therefore, currently we observe a dynamic growth of brain fitness industry, i.e. field offering brain exercises for healthy individuals. The development of this industry would be impossible if not for globally increasing interest and associated number of BCI-based devices. In practice, BCI technology is based on three paradigms: SCP, i.e. slow cortical potentials [2], induced potential P300 and ERD/ERS – event related desynchronization/synchronization [1].

Brain computer interfaces, due to correlation with external event (or lack of it), may be divided into asynchronous – based on spontaneous brain activity not related to an external event, and synchronous – related to occurrence of external event. The conducted literature review indicates that development of BCI technology determines creation of a constantly increasing number of software solutions for signal analysis and identification [7], as well as prototype products for showing changes of brain electric activity using LEDs [6].

2. Brain-Computer Technology in Video-Gaming Using FFT

Brain-computer technology in a non-invasive version gains more and more possible practical applications in different domains of life, including neurogaming [4]. The main advantage of this technology is a possibility to affect game action using only brain signals without using them directly to trigger effector muscle of given limb, which is the case in standard controlling. As shown by the literature review, one of the first neurogames was NeuroRacer, aiming to develop cognitive abilities. Studies conducted using the game allowed to draw a conclusion that people playing the game significantly improved their working memory and cognitive skills [3]. An important positive aspect from the game was also enhancing the multitasking capacity for mental operations, a decline of which is particularly observed in the elderly.

The performed analyses indicate that neurogaming has a relatively low competitive level due to the presence of large delays between signal transmitted from the surface of human head to a work station, and due to occurrence of measurement artifacts that are hard to eliminate in practical applications. This requires use of proper signal filtering. One of them is FFT (Fast Fourier Transform). This involves transforming process which gives a transform as a result. Fourier Transform determined for discrete signal, i.e. signal based on specific number of samples is called Discrete Fourier Transform. If x_0, …., x_{N-1} are complex numbers, the DFT can be expressed in the following form (1).

$$X_K = \sum_{n=0}^{N-1} x_n e^{\frac{-2\pi i}{N} nk},\ k = 0,\dots,N-1 \tag{1}$$

One of the components of Fourier series is a harmonic component that represents the signal in spectral domain. By using DFT, signal samples a_0, a_1, a_2, a_3, …, a_{N-1}, assuming $a_i \in R$ are transformed into series of harmonics A_0, A_1, A_2, A_3, …, A_{N-1}, assuming that $A_i \in C$, it is done according to equation (2), where i – imaginary unit, k – harmonic number, n – signal sample number, a_n – signal sample value, N – number of samples.

$$\begin{aligned} A_K &= \sum_{n=0}^{N-1} a_n w_N^{-kn},\ 0 \le k \le N-1 \\ w_N &= e^{i\frac{2\pi}{N}} \end{aligned} \tag{2}$$

When conducting FFT analysis, one should remember that biological signals are never sinusoidal signal, but rather a component of many. FFT analysis enables quick and accurate identification of signal components. Fig. 1 presents example of FFT analysis conducted using Emotiv TestBench. Data were taken from O2 electrode for maximum signal amplitude in range 80 to –60 dB.

Figure 1 presents signal as gain and frequency, while on the right hand side there are classifications

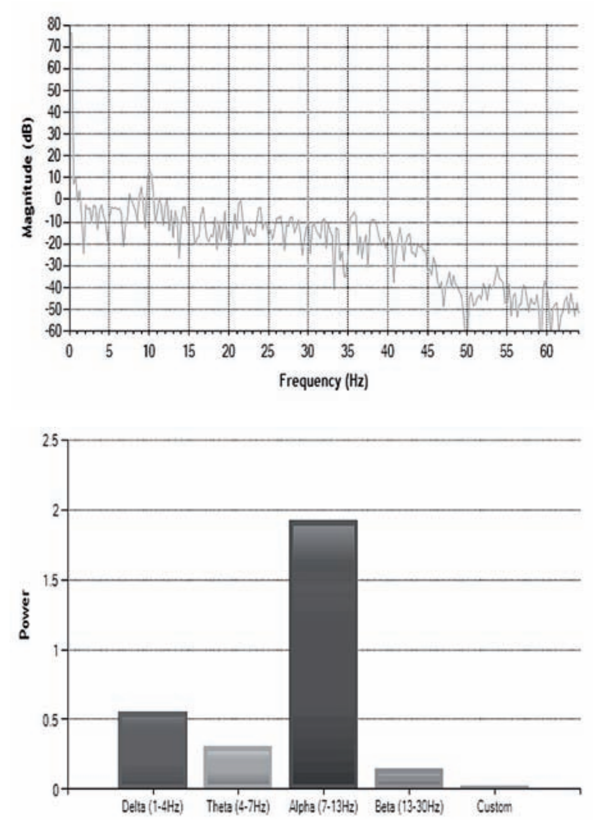

Fig. 1. FFT analysis of signal using Emotiv TestBench application

of individual rhythms of brainwaves for signal in gain-frequency plane. High activity of alpha waves in range from 7 to 13 Hz is clearly visible here. This is related to idle/relaxed state of the test subject. For comparison, range of beta waves is in this case very low, which is related to no information processing in a given time window. Thus it can be concluded that FFT analysis provides correct signal filtration and identification of activity of given brain wave ranges for specific electrodes for the neurogaming purposes.

A dynamic development of games implies also need of increasing number of signals recognised by brain-computer interfaces.

The studies conducted at the Laboratory of Neuroinformatics and Decision Systems of the Opole University of Technology involved use of 14 channel electrodes + 2 reference electrodes contained in the Emotiv EPOC+ NeuroHeadset device presented in Figure 2. This device does not require use of gel or conductive paste, however, saline solution is helpful in its correct operation by saturating elements (felts) at skin-electrode contact [5]. An important factor in ensuring correct device operation is that it must be properly placed on the head of the test subject as presented in Figure 2. Device speed and accuracy is ensured by sampling 2048 times per second, and sample filtration. Once the sampling process has been complete, 256 samples per each channel are obtained with the maximum resolution of 16 bits. The device performs FFT filtration. Frequency the device responds to is in range from 0.16 to 43 Hz, which allows, *inter alia*, to read state of: meditation, idleness, boredom and concentration.

Fig. 2. Emotiv EPOC+ NeuroHeadset and visualisation of placement of the device on head of the controlling person

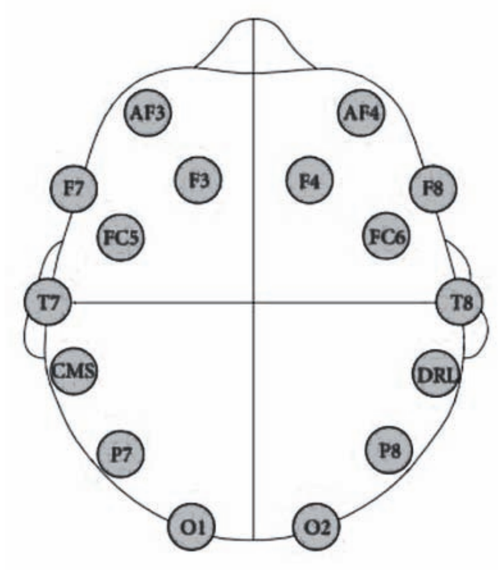

Fig. 3. Location of electrodes on the head of the subject in accordance with standard 10-20 for Emotiv EPOC+ NeuroHeadset with identifiers

The electrodes are located on the head of the controlling person based on international system 10-20, as shown in Figure 3. It should be noted that CMS and DRL are reference electrode and grounding electrode, respectively. Other electrodes following the standard of the International Federation for Clinical Neurophysiology have (in their elements) even numerical identifiers for right hemisphere and odd ones for left hemisphere, as well as letter identifiers based on brain lobes they are connected to.

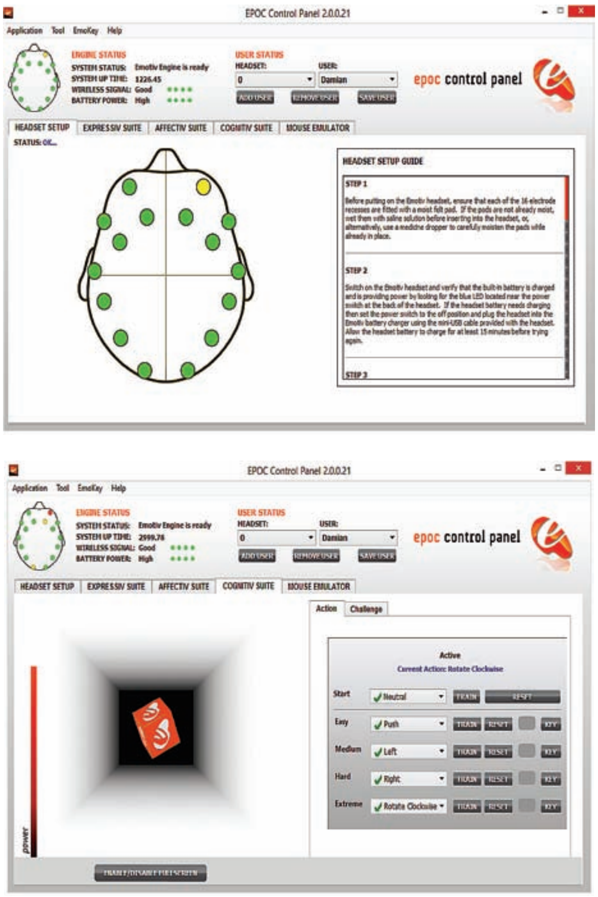

Fig. 4. Head outline in the main window of EPOC Control Panel and cognitive training performed in Cognitiv Suite tab

In terms of controlling avatars in a virtual reality, there is still a problem with the BCI today as device-user calibration is a very time-consuming process that must be performed prior the commencement of controlling. In order to identify control signals after placing the device on the head of the test subject correctly, it is necessary to run EPOC Control Panel app to verify the connection status and thus proper correlation at skin-electrode interface for all 16 electrodes presented in the visualisation (Figure 4, left-hand side). EPOC control panel should be also used for performing cognitive training, effect of which can be used in neurogaming applications. Cognitive training involves archiving brain activity in a given time in correlation to a specific event, and then comparing archived patterns with observed events. For the performed tests, it was necessary to identify brain activity in relaxed state and increased mental effort aimed at movement in a specific direction (north, south, east, west) shown in Figure 4 – on the right side, marked by a cube in 3D space.

3. Virtual Reality – VR

Virtual reality originated in the 1960s. However, recently its development became much more dynamical due to the appearance of new technological solutions such as goggles that can display pictures both in 2D and 3D mode. Such goggles have two miniature screens, each of them showing a proper part of the image. From the practical perspective, virtual reality can be defined as a combination of special equipment and software. Software solutions play a role of supporting hardware accelerators in scope of transforming environment into image, which implies large amount of mathematical computations. However, hardware solutions may support immersion, i.e. dive deeper into generated virtual reality.

Currently, visualisation of virtual reality is based mainly on implementations used in devices produced by Oculus. Unfortunately, as shown by experiments so far, this technology does not currently allow experiencing virtual reality for longer periods of time, as it is fatiguing to human body, particularly to eyeballs.

4. Concept of Combining VR with BCI for the Video Gaming Purposes

Unfortunately, present-day use of BCI for neurogaming requires aforementioned concept of controlling using additional controllers. This is mainly due to the difficulty in distinguishing information from electroencephalography tests for controlling game action, based on several different mental states. However, it is worth noting that for such neourogaming tools as Spirit Mountain (Figure 5) by Emotiv Inc., application of the BCI technology proved to work very well in practice, which was confirmed by tests conducted in the Laboratory of Neuroinformatics and Decision System of the Opole University of Technology. This is caused by the fact that number of handled

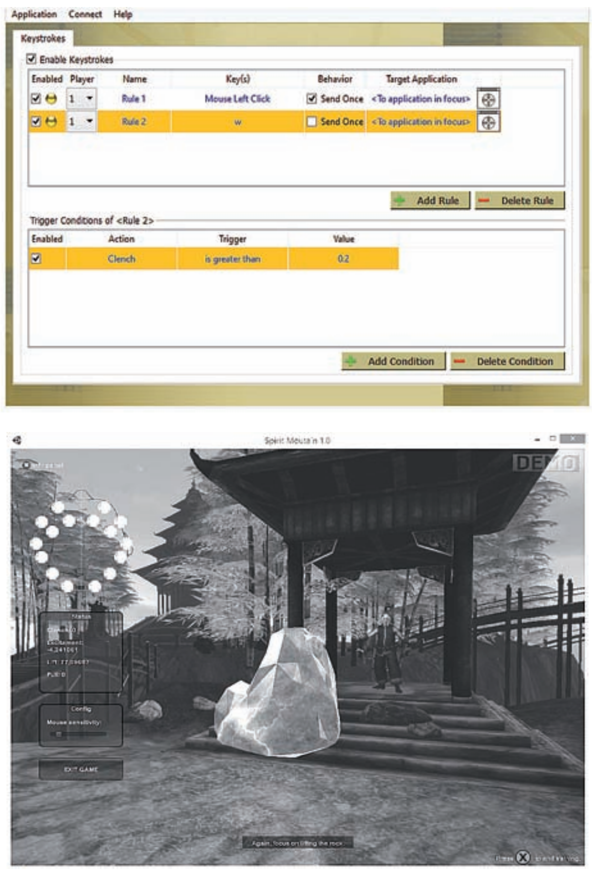

Fig. 5. Main window of EmoKey application and example of virtual environment Spirit Mountain created using Unity engine

actions is rather low. In a virtual world modelled in this application, it is possible to move objects by thinking. Moreover, one can move objects in relation to each other by focusing his or her attention. The game is based on the world exploration using internal imaginations based on the induced potentials that are additionally supported by gyro, which is a part of equipment of Emotiv EPOC+ NeuroHeadset. This is because the manufacturer wishes to improve sense of first-person game-play, and to eliminate mechanical components such as computer mouse from controlling process.

In order to perform tests of neurogaming applications based on BCI technology which is used by Emotiv EPOC+ NeuroHeadset, it was necessary to correlate buttons with some specific human mental states as presented in Figure 5. The conducted tests indicate that controlling virtual objects using brain is a complex and difficult process. Additionally, there is a delay during information transfer, which has negative impact on the controlling process.

Cerebral Constructor was another tested neurogaming application involving Emotiv EPOC+ NeuroHeadset for the purposes of this experiment. In this case, controlling allowed identification of seven brain activity states associated with moving up, down, left and right, lifting, pulling and lowering used for rotating a given object. As shown by the performed tests from the practical perspective, there are only three commands: one for rotation and two for moving.

In case of applying the BCI technologies for games other than neurogaming ones, there are some problems arising, mainly related to the lack of direct correlation between the products.

Another important problem in terms of virtual reality operation is the lack of model cooperation of human body with the technique. For sense of sight there is an identified issue of lagging – delay that occurs between head movements registered by VR goggles and an image generated on the display of workstation. Another problem is related to anatomical labyrinth and its erroneous identification of orientation in relation to gravity as compared to the orientation calculated by the algorithm operating in a given app. Another issue is the fact that image is created by VR goggles at fixed distance from the participant, which is a rather different approach than real reality, where we focus sight on objects located at different distances from us.

In case of combination of devices based on the BCI technology such as: Emotiv EPOC+ NeuroHeadset with VR goggles, it is worth keeping in mind that artifacts may occur if both devices are placed close to each other. VR goggles operation causes small changes in operation of Emotiv EOPC+ NeuroHeadset, which in the end allows to control the character using the virtual reality. There are currently simulator prototypes using combination of these devices. It is possible to move in these simulators by using generated internal events that to some extent (in a general sense) can be seen as thoughts.

As indicated by the literature review, in the future it should be possible in the future to use electromyography (EMG), i.e. diagnostics of the electrical activity of muscles and peripheral nerves, for determination of body behaviour in a given moment, and converting this information into movement of the avatar. Moreover, the proposed hybrid solution can be supplemented with EOG, i.e. electrooculography that recognizes data on resting potential around eyeballs in order to verify the current looking direction in the virtual reality that surrounds the subject.

There are also attempts to combine BCI-based devices with augmented reality (AR). This technology allows us to observe the surrounding world on the streets combined with elements produced by virtual reality. Augmented Reality is based on combination of two-worlds, real-time interaction, and freedom of movement in three dimensions. It is worth noting that there is an increasing number of AR-based classes taught at the Massachusetts Institute of Technology (MIT) and it is just one of such higher education institutions. Students use their smartphones and GPS devices to gradually explore the campus area that has been enhanced with information to assist learning. Augmented reality can be used in: education – allows gaining information from objects used by students via immediate verification and electronic data-based feedback; medicine – access to data on the internal organ structure of the examined person; marketing, and robotics – by identifying objects that make up the environment in which a robot moves, and supporting generation of potentials in a brain of a person controlling the robot using BCI in a feedback loop [8].

5. Summary

It is worth noting that neurogaming is currently widely used in treating mental disorders such as attention deficit hyperactivity disorder (ADHD), and Post-traumatic stress disorder (PTSD). Increased interest in neurogaming in the world has resulted in organisation of periodic conference held in San Francisco, USA, where the topics related to the ones mentioned above are discussed. Neurogaming, just as other practical applications of the brain-computer interface technology, raises ethical controversies. There are dilemmas concerning potential gaining/taking control over human mind by a machine or an individual [9]. However, in the perspective of brain fitness, it becomes a promising tool which was confirmed by tests conducted for the purposes of this paper.

Actually there are many practical implementations of technology based on augmented reality among other things in the entertainment industry for the construction of urban games. BCI technology, which develop rapidly for several years, are an excellent example of a technology that is in line with the virtual reality. This technology may be an interesting tool among other things for the implementation of control processes including avatars. Controlling by means of the human mind without the use of evoked potentials is difficult in terms of implementations in everyday conditions as evidenced by the author's studies. In practise it is easier to control the output of evoked potential and thus the accuracy is higher. In the BCI technology the classification takes longer time, so the game is slower.

AUTHOR

Szczepan Paszkiel – Department of Electrical, Control & Computer Engineering, Institute of Control & Computer Engineering, Opole University of Technology, Opole, 45-316, Poland.
E-mail: s.paszkiel@po.opole.pl.

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